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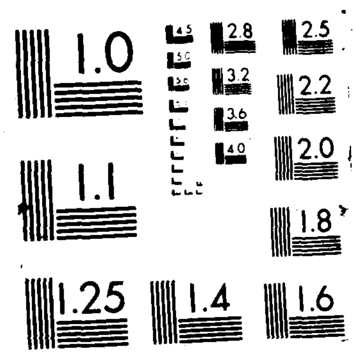
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Final Technical Report

1. HEL PROPOSAL NUMBER: Final Progress Report.

2. PERIOD COVERED BY REPORT: March 1986 to March 1987.

3. TITLE OF PROPOSAL: Research on Visual Information Processing with Special Reference to Oculomotor Behavior in the Areas of Exploration, Recognition and Search.

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5. NAME OF INSTITUTION: Applied Science Laboratories.

6. AUTHOR OF REPORT: Dr. Leonard F.M. Scinto.

7. LIST OF MANUSCRIPTS OR REPORTS COMPLETED DURING THE TERM OF THIS REPORT:

"Allocation of Focal Attention During Fixation and the Recognition of Non Pre attentively Discriminable Texture Elements at Various Retinal Locations." Document No. ASL - R - 0187.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT:

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The research proposed under this project sought to understand certain fundamental aspect of visual information processing in the areas of recognition, exploration and search behavior. Over the course of the six months during which work was under taken and the subsequent five months of wind up activity progress was made in the following areas.

I. Laboratory Reconfiguration:

At the conclusion of previous research at HEL it became obvious that certain equipment modifications would be necessary to continue and expand the research capabilities of the eye movement laboratory facilities. During the six months of this contract ASL undertook to upgrade and augment the eye movement recording equipment at HEL.

Major projects included the building and installation of a second optical head in a vacant subject chamber, the installation of an extended head tracking module in the optical head already in place at the laboratory.

Each of these projects entailed considerable effort to correct data collection short comings of the previous installation. New pedestal mounts were sought in order to better stabilize the optical heads of the data acquisition equipment in order to overcome vibration problems, all optical heads were remounted in such a way as to overcome overheating problems, a new CCD camera was installed to improve imaging accuracy, consultations were held with optical experts to explore ways to overcome inherent problems in projecting stimulus material on the screen in the subject chamber and new cabling was laid to connect both optical heads.

As a consequence of the changes and improvements discussed above and in light of the projected arrival of new computational equipment for data acquisition and processing the main data acquisition software had to be rewritten. The CAPTURE program rewriting in Fortran was completed in late July 1986. Other minor software revisions as well as data processing software was written during the time of this contract. One major effort was devoted to writing a data acquisition program to record and analyze pupil diameter data. In conjunction with R. Lambert discussions were held about a design for a new data path from the ASL equipment at the HEL facility to the computer. This was under taken to lessen dependence on the white light system hardware for which there was no ongoing support. Routing data lines through this equipment in the past had caused delays in experimentation when this equipment experienced breakdowns.

II. Data Collection & Analysis:

The major experimental effort under taken during this period involved the completion of experiments begun earlier in the year on mapping of recognition rates for various retinal positions. These experiments were under taken to clarify some issues that arose as a consequence of a model of visual search we had developed during previous research at HEL.

In order to be able to run this experimentation an entirely new hardware and software data acquisition environment had to be designed and built and a new I/O configuration designed for the PDP 11 computer. This work was accomplished in March of 1986. Significant new data acquisition software was written to automate running of this experiment, to acquire subject data and to pre process the data once collected.

Once all necessary design and development work was completed we did pilot testing at the end of March. Data collection began in April of 1986 and completed by early May. At this time we began extensive analysis of the data we had obtained.

Subsequent months were devoted to the analysis of the retinal mapping data which presented significant problems. Some time was spent in assessing appropriate analysis models for the data. Problems with the SPSS-X procedure were encountered at BRL which did not allow us to analyze the data on the CYBER system. This necessitated preparing data tapes that could be mounted and run on a system at Harvard University. During the period when analysis was taking place were began to incorporate the hardware and software changes spoken of above.

Work on this contract was suspended during August. Subsequent time has been devoted to finishing work on the analysis of data as well as software documentation. The results of the analysis of this data are incorporated in this report in Appendix A.

Appendix A

Table of Contents

List of Figures

Allocation of Focal Attention During Fixation and the Recognition of Non Pre attentively Discriminable texture elements at Various Retinal Eccentricities.

Leonard F.M. Scinto

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1987

1 Introduction:

In an earlier study, Scinto et al. 1986, we posited the existence of two levels of visual attention allocation in a search task involving non pre attentively discriminable texture elements. We termed these respectively macro attentional shifts and micro attentional shifts. Macro attentional shifts we argued were characterized by the successive displacement of eye position to fixate and foveate necessary visual information. These macro shifts occur when the stimulus field or some information within that field is too large to be encompassed by a single fixation. Micro attentional shifts occur as attention shifts of focal attention within the effective visual field of a single fixation when parallel processing of the information in this field is inadequate to extract necessary information.

In the study cited above we sought to develop an algorithm to simulate and model the process of search for non pre attentively discriminable targets. The algorithm developed in that paper was based on a modified random walk that appeared to adequately model the kind of macro attention shift we have defined above. However, this algorithm left undetermined the process of focal attention allocation within a single fixation. This is a critical step in constructing an empirically adequate algorithm as we must be able to specify not only the probability of fixating a target but also the probability of recognizing the target should it fall within the fixation field. Figure 1 below gives a concrete illustration of this point. In this figure the circle represents the highest acuity area of the fixation some four degrees in diameter. Within this area are a number of texture elements that form a ground and some that constitute the target (in this case an array of 14 elements two of which differ from the ground and form the target). If focal attention is necessary to discriminate the target element or elements from the ground each element must be scrutinized in serial by such focal attention. If as Julesz, 1985 and others have demonstrated shifts of focal attention take approximately 50msc and the aperture of focal attention can encompass one element at a time, a minimum of 700msc would be required to exhaustively scan this array. Our work has shown that the average fixation is only about 270msc in duration. In that case only about 5 or 6 elements of the array can be attended to during a single fixation. Further, it is unclear if the full durational of the fixation is available for processing retinal information. See for example the comments by Salthouse, 1980 on the determinants of fixation durations.

The question arises as to whether the allocation of focal attention within the effective field of the fixation is based on a random process and further whether the position of the target element in the fixation array affects the amount of time needed to discriminate that element and recognize it as a target element.

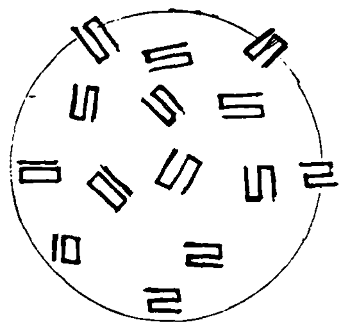

Figure 1: Fixation Array with 14 Texture Elements

If it were the case that position within the fixational array did not matter for recognition then the allocation of focal attention or what we have termed micro attentional shifts could best be modeled by a random walk process. However, a number of researchers (Payne, 1966; Lefton & Haber, 1974; Eriksen & Schultz, 1977) have demonstrated that with increasing distance from foveal center recognition time for pre attentively discriminable elements increases by as much as 100msc for three degrees from foveal center. Eriksen & Schultz speculate that the observed differences may be due to differences in neural transmission time from positions on the retina to higher information processing centers or a degradation in the information provided higher processing centers from retinal locations away from foveal center. Sterling and Salthouse (1981) in a study of retinal location and visual processing rate concluded that with positions removed from foveal center there is no decrease in the rate of information extraction at such positions but rather that the reduction in number of receptors at locations away from foveal center increases the time necessary for the establishment of an initial representation of a stimulus. Once a representation of the stimulus has been established discrimination say between two alternatives is not affected by retinal locus.

Of further note is the work on spatial mapping of projection from the retina to primary visual cortex (Marshall, 1941 & Daniel & Whitteridge, 1961). Whereas the density of cells in the cortical surface is fairly constant (Dow et al., 1981) an image of constant size at various eccentricities from foveal center on the retina will give rise to progressively smaller projections on primary visual cortex thus stimulating fewer cortical cells. Observed differences in recognition rates may in part be accounted for in this fashion.

In their work on texture discrimination and vision Julesz and his colleagues (Julesz, 1975; 1980; 1981; 1985; Julesz & Bergin, 1983; Bergin & Julesz, 1983; 1983a) isolated a number of features of elementary texture elements they termed textons. Texture elements were found to be non pre attentively discriminable only if these texture element did not differ in the local density of textons. Julesz isolated a number of such textons such as number of line segments, number of line ends and number of crossings. In a series of experiments exploring the discriminability of pairs of texture elements (Bergin & Julesz, 1983; Bergin & Julesz, 1983a) reached the following conclusion. They state 1983:2

> The discrimination behaviour described is independent of whether the stimulus falls entirely within the fovea or extends into the near periphery. This was tested over a range of a factor eight in size using stimuli consisting of seven elements arranged randomly in a ring centered at the fixation mark...The smallest of these stimuli subtended only 2.8 of visual angle while the

largest was nearly 22 in diameter...this uniform contraction or dilation of the stimulus had little effect on performance. Thus, within the limits imposed by spatial resolution, the stimulus can be viewed from a wide range of distances with similar results... This suggests that except for the change in spatial scale, the fovea and near periphery function similarly in the extraction of visual information [Emphasis added].

On the surface this statement by Bergin & Julesz would appear to suggest that if texture element are well above acuity threshold then they should be equally discriminable either in the fovea or "near periphery". However, the Bergin & Julesz experiments restricted inspection time to a minimum of approximately 100msc to about 550msc. Performance in the task requiring subjects to report whether a target texture element was present in an array of seven texture elements never exceeded 62% correct at the maximum time allowed for inspection. Given the conclusion we cited above by Sterling & Salthouse, increasing the stimulus size by almost a factor of ten and allowing some 500msc for inspection, it should not surprise us that recognition rates for this experiment were similar for that where a smaller stimulus set was used. We must assume that in this experiment viewing distance did not change as they do not report a figure for viewing distance. Given that viewing distance remains constant the number of receptors stimulated in the periphery is greatly increased thus allowing for an initial representation of the stimulus to be formed sooner than ordinarily be the case with a smaller stimulus impinging on fewer receptors. Additionally the work on spatial mapping of retinal images to primary visual cortex suggest that, factors of spatial contrast etc. aside, increasing retinal image size will lead to similar numbers of cortical cells being stimulated at greater eccentricities from foveal center. However, the experimental situation posed by Bergin & Julesz is hardly representative of normal viewing situations and the claim that the fovea and near periphery function similarly with respect to information extraction is somewhat misleading with the caveat of change in spatial scale.

It is unlikely that a single fixation will much exceed 300msc in duration. It is more unlikely that fixations of 500+msc will be found in most inspection or recognition tasks. In light of this and the findings cited earlier about the effect of retinal position on recognition times it is clear that in normal viewing where stimulus size decreases with greater eccentricity from foveal center the fovea and near periphery do not function behaviorally in an similar manner. Neural principles of information extraction and image formation may be equivalent but there are non trivial perceptual differences to be observed.

In an effort to determine the nature of the process of focal attention allocation within a single fixation we designed an experiment to determine the recognition rates for a pair of non pre attentively discriminable texture elements. This pair of texture element were the same used in our search study (scinto, et al., 1986) and consisted of an element yielding the percept of a 10 and an element yielding the percept of an S. These elements share the same first and second order statistics and do not differ in the local density of textons, same number of line segments and same number of terminators. In order to discriminate these elements, when they are presented briefly one needs to attend to each by the allocation of focal attention. Figure two below gives an example of these texture elements and the horizontal and vertical orientations in which they appeared in our experiment. Our hypothesis was that texture elements that appeared further away from the center of fixation and hence from the center of the fovea would be progressively more difficult to recognize as indicated by recognition error rate. Error rates should show a steady increase as elements appeared farther away from foveal center. It has been demonstrated in many cases that as the number of elements in an array is

S-OR-I 10-OR-I S-OR-II 10-OR-II

Figure 2: S and 10 texture elements in Horizontal and Vertical Orientations

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increased the probability of detecting a target element decreases. In the case where a single fixation encompasses some nine to sixteen texture elements the probability of detecting any target texture elements will vary not only as a function of the number of target and non target elements in the array but also as a function of the retinal position of the target elements in this retinal array. With limited time available for allocation of focal attention during any given fixation, elements that are farther from center will consume more inspection time. With an array of ten elements and assuming 50msc for each shift of focal attention as predicted by Julesz, 1985 we might expect that as many as five elements could be exhaustively examined during a 250msc fixation. However, we hypothesize that if some of those elements appear some 2 to 3 degrees from foveal center they will require more inspection time and overall less then five elements will be inspected during that fixation. Such a prediction would explain the phenomena we have often observed in our search data where a fixation falls on target texture elements yet no target detection is reported. This is analogous to the often reported phenomena of looking without seeing.

2 Experimental Protocols:

The texture elements in figure two were those used in our experiments. As these texture elements share the same first and second order statistics and do not differ in the local density of textons the preattentive visual system cannot discriminate between them (Julesz, 1983). In order for discrimination to take place they require focal scrutiny by the attentive visual system. When these elements appear in some position in a fixation retinal array it is necessary to shift focal attention to that location for discrimination and recognition to occur.

In this experiment we mapped forty eight retinal positions disposed along the major horizontal and vertical axes around a central fixation point in foveal center. Each of these positions were spaced 1 apart and represented positions along each axis of from 1 to 6 from foveal center as represented by the fixation cross. A representation of this fixational array appears in figure 3. Each of the two texture elements in their two orientations (horizontal & vertical) appeared at each retinal position mapped. All texture elements were randomly disposed at each of the forty eight retinal positions. This randomization was done for each subject for each trial the subject viewed. Subjects viewed ten trials for each texture element and its two orientations for a total of 480 elements.

Texture elements were presented by means of 35mm back projected slides. The elements were viewed from a distance of 1.75m on a screen 56.5cm by 57.1cm. The texture figures subtended 2/3 of arc on the screen. The measured contrast ratio of the texture elements at any of the forty eight positions did not vary significantly. Calculations of the projected angle of the texture elements on the retina showed that this angle did not vary significantly. The measured angles and widths at the retina for the

forty eight elements is given in table 1. All texture elements at the six positions along any given axis were easily resolvable and well above acuity threshold levels.

Table 1

Axis & Position	Angle at Eye	Width at Eye(mm)
I-1	40'24"	.19978
I-2	40'22"	.19961
I-3	40'19"	.19936
I-4	40'16"	.19912
I-5	40'12"	.19879
I-6	40' 8"	.19846
II-1	40'15"	.19903
II-2	40' 6"	.19829
II-3	39'55"	.19739
II-4	39"44"	.19648
II-5	39'33"	.19557
II-6	39'21"	.19458
III-1	40'24"	.19978
III-2	40'22"	.19961
III-3	40'19"	.19936
III-4	40'16"	.19912
III-5	40'12"	.19879
III-6	40' 8"	.19846
IV-1	40'31"	.20035
IV-2	40'39"	.20101
IV-3	40'45"	.20151
IV-4	40'50"	.20192
IV-5	40'54"	.20225
IV-6	40'57"	.20250

Measured Angles and Widths of Texture Elements at the Eye

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2.1 *Presentation Sequence:*

The presentation sequence for any experimental session ran as follows. Subjects first saw a central fixation cross with a duration of three seconds followed at once by the stimulus element with an exposure time of 100msc. After the stimulus element there was a blank but lighted screen for 160msc followed by an erasing mask with a duration of three seconds. The series then began again with the central fixation cross. The combination of the stimulus presentation time of 100msc with the blank time of 160msc allowed subjects 260msc for a shift of focal attention to the projected texture element and focal scrutiny of the element. This interval of 260msc corresponded to the average fixation time found in our search study.

In each experimental session subjects viewed four trays (session one contained an extra practice tray) of forty eight slides per tray. Subjects participated in five sessions over two and a half days with one session per morning and afternoon. There were a total of ten trials for each figure for each orientation of the figure at each retinal position mapped.

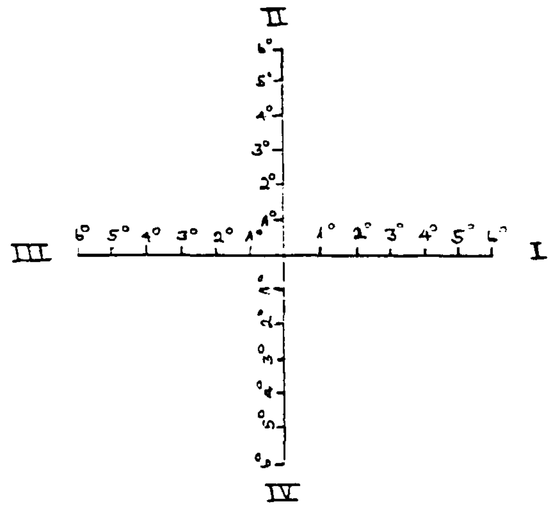

Figure 3: Map of forty eight Retinal Positions on Four Axes

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2.2 Experimental Task:

Subjects' task was to correctly identify which texture element was presented at any given trial. Subjects were instructed to respond as quickly as possible once they knew which element had been presented by pressing a response button with their dominant hand and after this to verbally inform the experimenter which element had appeared. Each subject was instructed to guess what the element was on any trial where the subject was uncertain.

2.3 Dependent & Independent Variables:

The main dependent variable was the percentage error rate for identification of texture elements based on the ten trials for each element at each retinal position. There were four independent variables: texture figure (C or 10), distance from foveal center (1 to 6), axis (1 to 4), & figure orientation (horizontal or vertical). This yielded a (2 x 6 x 4 x 2) repeated measures design. All subjects viewed all experimental conditions and presentation order was randomized for each subject on each trial for all the conditions. All stimulus presentations were monocular to the subjects dominant eye as determined by pretesting. All stimulus presentations were controlled by the laboratory PDP-11 computer and data collection was also controlled by the computer.

3 Subjects:

A total of fourteen subjects were used in this experiment. Subjects were adults with normal or corrected to normal vision. If subjects wore corrective lenses they wore these during experimentation. No subjects reported any difficulty in resolving the texture elements given sufficient.

4 Subject Studio:

The viewing studio was a room measuring 2.48m X 3.05m containing a chair and table on which were situated a chin rest and response buttons. The viewing distance of the subject seated at the table to the screen was 1.75m from the screen. The total area of the screen subtended an angle of 18 degrees horizontally and 18 degrees vertically. During experimental trials the only illumination in the room was from the screen so as to prevent any peripheral distraction. In order to stabilize head and eye position subjects used a chin rest during experimental trials. Random checks of eye position using an ASL model 1998 Eye View Monitor showed that subjects were able to maintain fixation on the central fixation cross during experimental trials.

5 Results:

Summary error rates were compiled based on the ten trials for each stimulus element in each of the four experimental conditions. Table two details the mean percent error rates standard deviations and variances summed over the fourteen subjects by texture figure, orientation, axis and distance from foveal center.

Based on the percent error scores we developed a program to plot the effective visual conspicuity area for each of the texture elements in their various orientations. These conspicuity areas correspond to the four experimental conditions. The program fit a curve (effectively an ellipse) to the four axes on which we tested. The intercepts for the curves on each of the axes were determined by using the distance from foveal center at which the error rates exceeded 50% and recognition performance approached chance levels. The six distances along any axis constituted the possible intercepts. In those cases where error rates on no axis exceeded 50% the program fit a circle at intercepts representing a distance of six degrees from fovea center. These representations were constructed primarily to graphically display recognition performance and are not meant to represent a rigorously mapped effective field of view. These retinal maps for all fourteen subjects for all texture figures are given in figure four below.

For all the texture figures we plotted the percent incorrect responses for the fourteen subjects across all axes by texture figure and orientation. These plots are given in figure 5. The plots show that with increasing distance from foveal center the error rates increase.

TABLE 2

Element	Axis	Orientation	Distance	Mean	sd	Variance
S	1	1	1	.00	.000	.000
S	1	1	2	.05	.073	.005
S	1	1	3	.30	.218	.047
S	1	1	4	.40	.310	.096
S	1	1	5	.43	.294	.086
S	1	1	6	.45	.279	.078
S	1	2	1	.02	.058	.003
S	1	2	2	.22	.220	.048
S	1	2	3	.33	.276	.076
S	1	2	4	.47	.263	.069
S	1	2	5	.47	.260	.067
S	1	2	6	.43	.225	.050
S	1	3	1	.02	.041	.001
S	1	3	2	.05	.098	.005
S	1	3	3	.14	.216	.046
S	1	3	4	.22	.224	.050
S	1	3	5	.23	.231	.053
S	1	3	6	.30	.210	.044
S	1	4	1	.02	.041	.001
S	1	4	2	.09	.138	.019
S	1	4	3	.15	.209	.043
S	1	4	4	.30	.293	.086
S	1	4	5	.27	.208	.043
S	1	4	6	.32	.231	.053
S	2	1	1	.02	.055	.003
S	2	1	2	.17	.186	.034
S	2	1	3	.34	.282	.079
S	2	1	4	.42	.295	.087
S	2	1	5	.49	.328	.107
S	2	1	6	.54	.289	.083
S	2	2	1	.03	.081	.006
S	2	2	2	.16	.123	.016
S	2	2	3	.45	.287	.082
S	2	2	4	.52	.254	.064
S	2	2	5	.52	.240	.057
S	2	2	6	.52	.239	.057
S	2	3	1	.08	.180	.032
S	2	3	2	.21	.255	.065
S	2	3	3	.46	.291	.085
S	2	3	4	.47	.290	.079
S	2	3	5	.55	.232	.053
S	2	3	6	.62	.239	.057
S	2	4	1	.07	.156	.024
S	2	4	2	.32	.314	.098
S	2	4	3	.42	.201	.040
S	2	4	4	.42	.265	.070
S	2	4	5	.43	.274	.075
S	2	4	6	.46	.205	.042

TABLE 2 cont.

Element	Orientation	Axis	Distance	Mean	sd	Variance
10	1	1	1	.01	.034	.001
10	1	1	2	.09	.138	.019
10	1	1	3	.13	.183	.033
10	1	1	4	.41	.258	.066
10	1	1	5	.40	.269	.072
10	1	1	6	.45	.306	.093
10	1	2	1	.01	.034	.001
10	1	2	2	.32	.249	.062
10	1	2	3	.55	.261	.068
10	1	2	4	.53	.286	.082
10	1	2	5	.55	.304	.092
10	1	2	6	.65	.222	.049
10	1	3	1	.05	.062	.003
10	1	3	2	.07	.079	.006
10	1	3	3	.19	.148	.022
10	1	3	4	.51	.232	.054
10	1	3	5	.64	.263	.069
10	1	3	6	.66	.296	.088
10	1	4	1	.03	.061	.003
10	1	4	2	.31	.192	.036
10	1	4	3	.60	.223	.050
10	1	4	4	.62	.260	.067
10	1	4	5	.62	.242	.058
10	1	4	6	.70	.218	.047
10	2	1	1	.09	.122	.019
10	2	1	2	.22	.131	.017
10	2	1	3	.40	.285	.081
10	2	1	4	.49	.291	.084
10	2	1	5	.49	.284	.080
10	2	1	6	.47	.321	.103
10	2	2	1	.03	.081	.006
10	2	2	2	.22	.185	.034
10	2	2	3	.27	.208	.043
10	2	2	4	.42	.254	.064
10	2	2	5	.47	.245	.060
10	2	2	6	.45	.266	.071
10	2	3	1	.02	.041	.001
10	2	3	2	.20	.194	.037
10	2	3	3	.27	.245	.060
10	2	3	4	.33	.223	.049
10	2	3	5	.32	.240	.057
10	2	3	6	.35	.271	.073
10	2	4	1	.02	.045	.002
10	2	4	2	.12	.103	.011
10	2	4	3	.29	.229	.052
10	2	4	4	.45	.215	.046
10	2	4	5	.56	.229	.052
10	2	4	6	.57	.240	.057

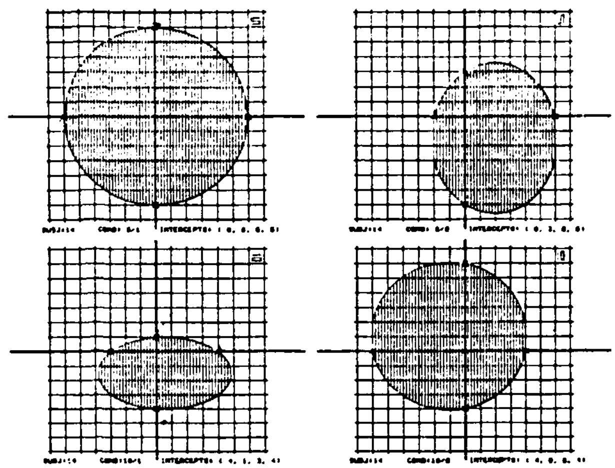

Figure 4: Retinal Maps for all Texture Figures for All Subjects

6 Analysis:

In order to determine if observed differences in recognition performance were significant we performed a multiverate repeated measures analysis using the procedure found in SPSS-X. The results from this analysis are found in table 3. This analysis showed strong significant differences for distance from foveal center, and angle of eccentricity (axis). This analysis also showed a strong effect for orientation of texture figure as well as several two way and three way interaction effects.

Table 3

Effect	df	F	P
Element	1/13	.43	.531
Orien	1/13	14.88	.002
Axis	3/39	15.36	.000
Pos	2/26	211.33	.000
El/Or	1/13	3.33	.091
El/Ax	3/39	.643	.592
El/Pos	2/26	.552	.582
Or/Ax	3/39	17.33	.000
Or/Pos	2/26	1.28	.294
Ax/Pos	6/78	4.31	.001

Table 3 (cont)

Effect	df	F	P
El/Or/Ax	3/39	9.127	.000
El/Or/Pos	2/26	4.369	.023
El/Ax/Pos	6/78	2.502	.029
Or/Ax/Pos	6/78	4.185	.001

Our expectation was that we should observe an effect for distance from foveal center. However, the finding of a significant effect for orientation and for angle of eccentricity from foveal center were not predicted. In order to better understand the effect for orientation we ran an additional MANOVA. In this MANOVA the data matrix was so arranged as to test whether the difference for orientation was due to the actual spatial orientation of the texture elements (horizontal vs. vertical) or rather to semantic or phenomenal orientational differences (the percept of an s or ten) by specifically contrasting the correct and incorrect orientations of these texture elements. This MANOVA showed that there was no significant effect for semantic orientation for the combined texture elements, df=1/13, F=3.333, P=.091. The complete results from this analysis are found in table 4.

Figure 6 plots the percentage correct responses for horizontal and vertical texture elements for all fourteen subjects across distance from foveal center broken out by axis. In these plots S and 10 texture elements are combined. Figure 7 plots the percent correct responses for all fourteen subjects across distance from foveal center for the semantically correct texture figures and semantically incorrect texture figures for each of the four axes. Figure 8 plots the orientation effect separately for S and 10 texture elements for all fourteen subjects across distance from foveal center. In figures 9 and 10 are plotted the significant two way interactions from the first MANOVA we ran. These figures plot Axis and Orientation by Position respectively. Figures 11 through 16 plot the significant three way interactions from this same MANOVA. In all these figures percent correct recognitions are plotted on the y axis.

In order to assess if the orientation effects observed in the analyses given above were indeed due to a difference in spatial orientation or rather to the difference in phenomenal orientation (the percept of an S or 10 as opposed to inversions of these) we ran two additional MANOVAs on the error rate data. In these MANOVAs we tested for effects separately for each of the two texture figures. In the analysis for the S texture figure we found a significant effect for orientation with the texture figure suggesting the percept of an S yielding better recognition performance. The full analysis table for the S texture figure is given in table 5. In the analysis for the 10 texture element the effect for orientation was not significant. There would appear to be no effect for the ten figure in its correct phenomenal orientation. The full results for this analysis are given in table 6. Figure 8 plots the recognition data for these two effects.

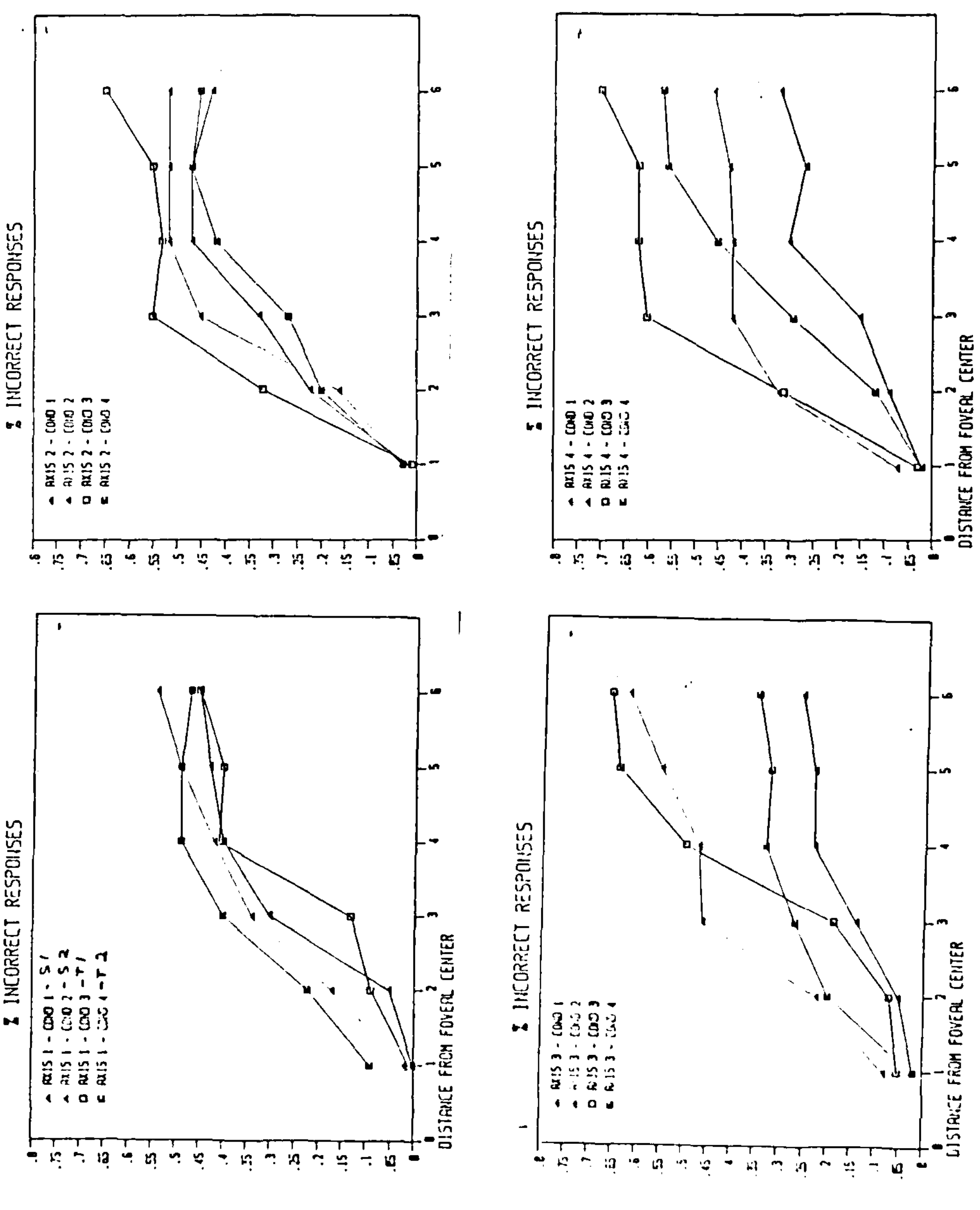

Figure 5: Error Rates by Figure & Orientation by Axis by Distance

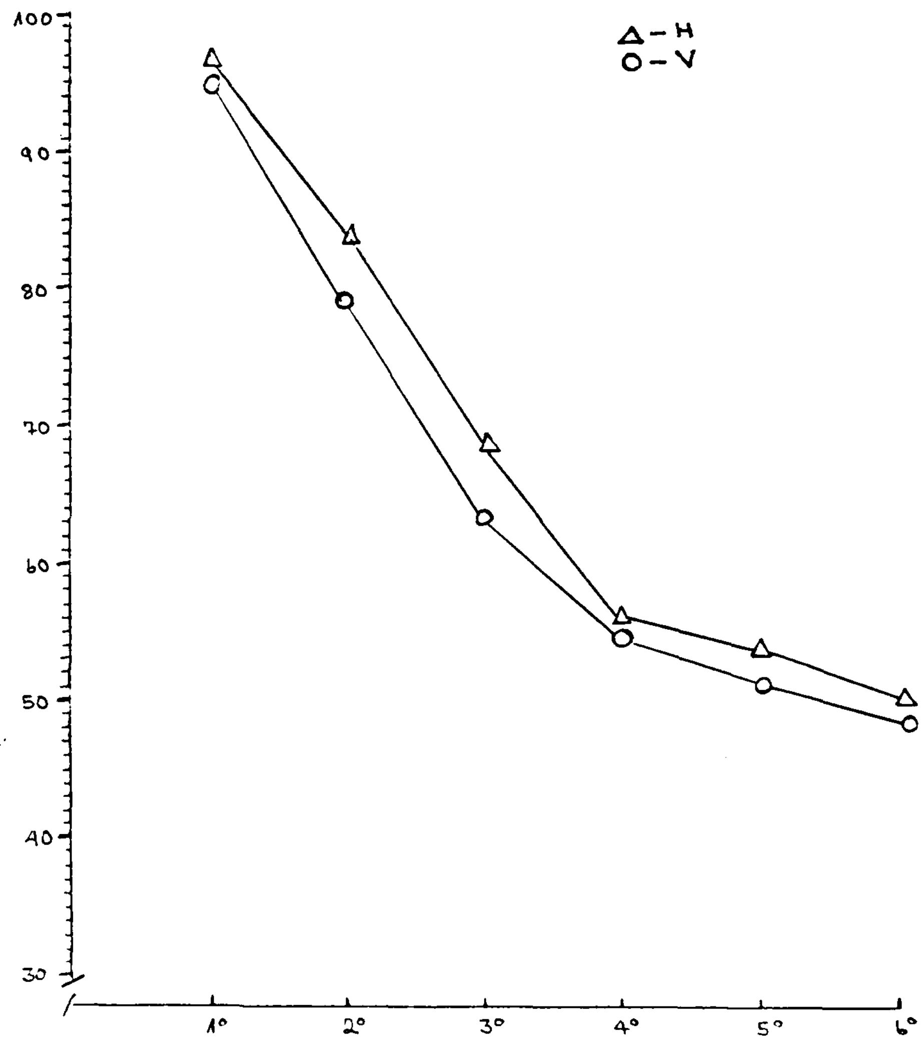

Figure 6: Percentage Correct Responses for Horizontal vs. Vertical Texture Elements across Distance from Foveal Center

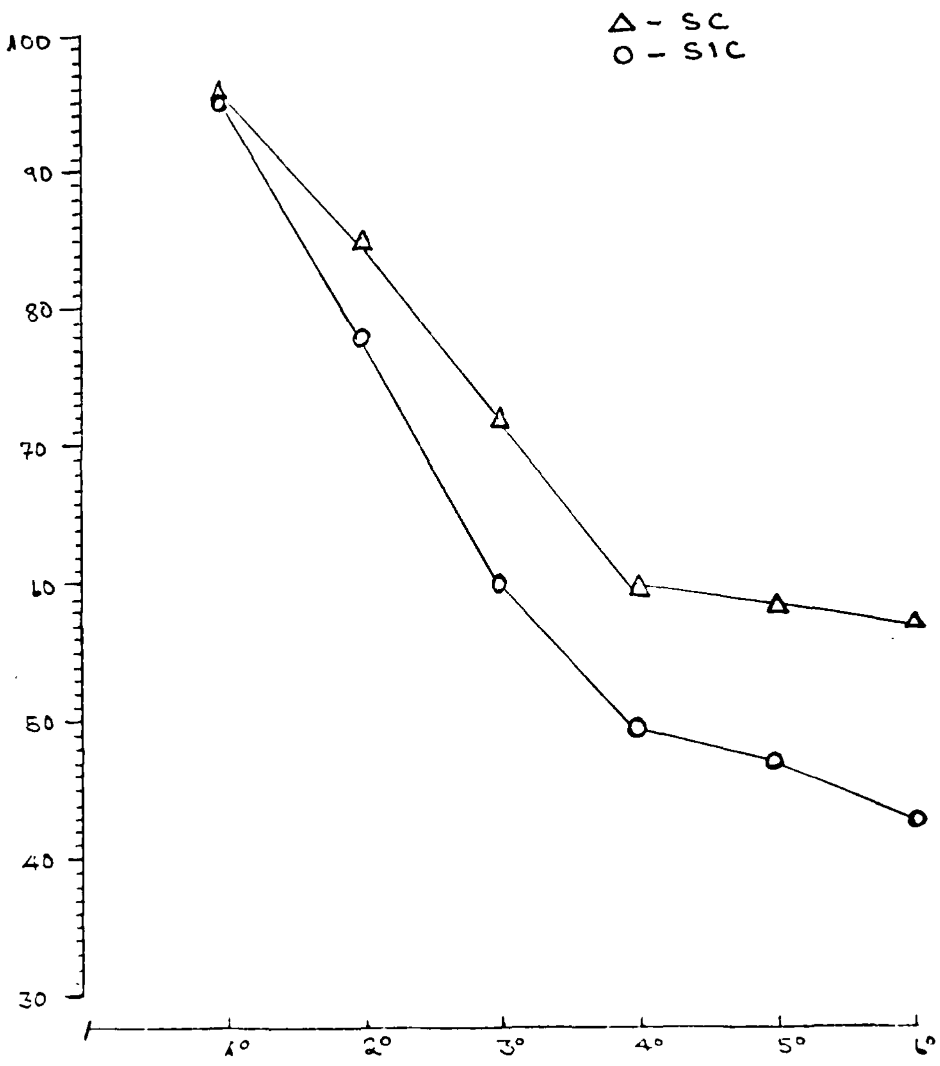

Figure 7: Percentage Correct Responses for Semantically Correct and Incorrect Texture Elements across Distance from Foveal Center

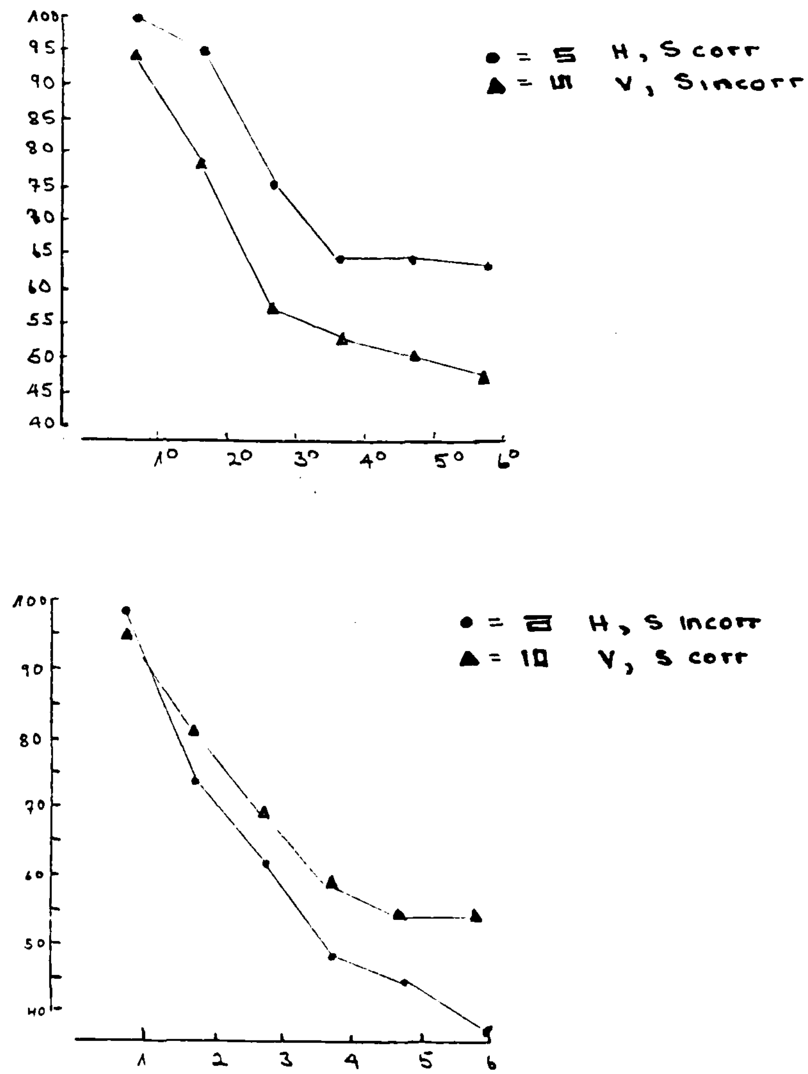

Figure 8: Percent Correct Responses across Distance from Foveal Center for Horziontal and Vertical Orientations for 5 and 10 Texture Figures

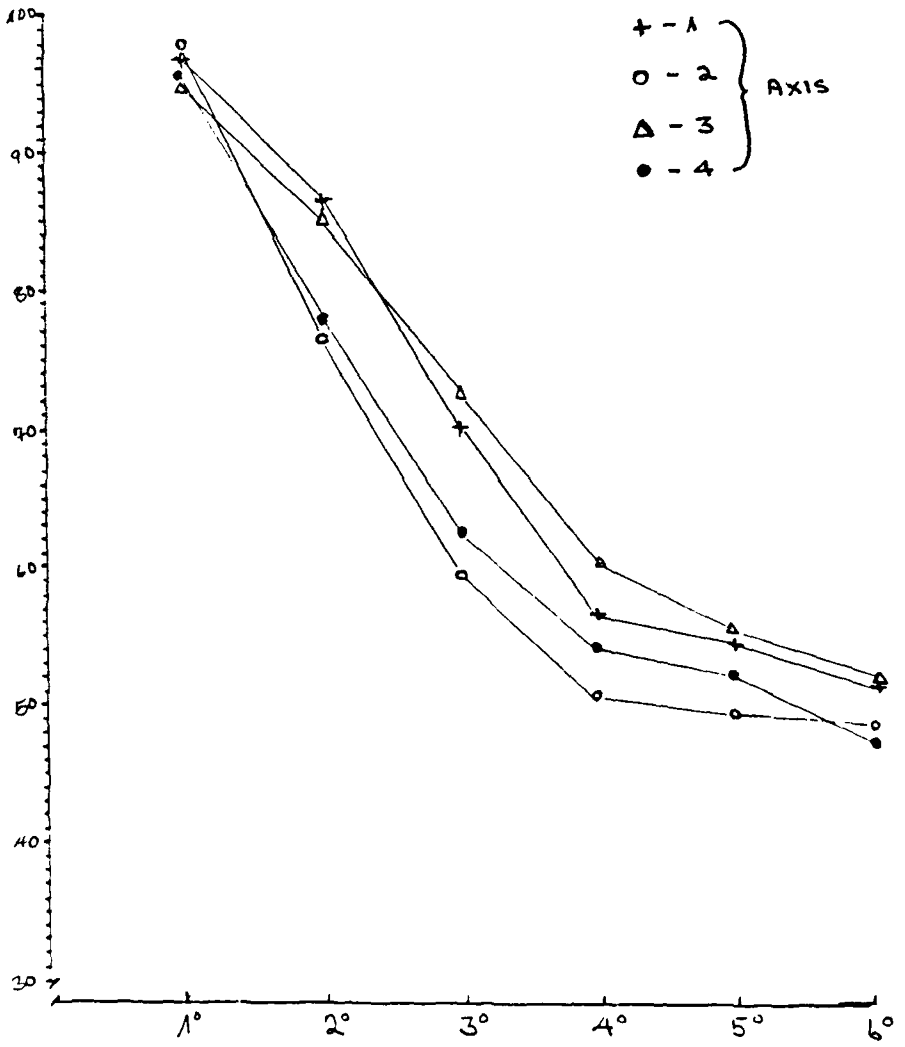

Figure 9: Percent Correct Recognition Responses for Four Axis by Six Distances from foveal Center

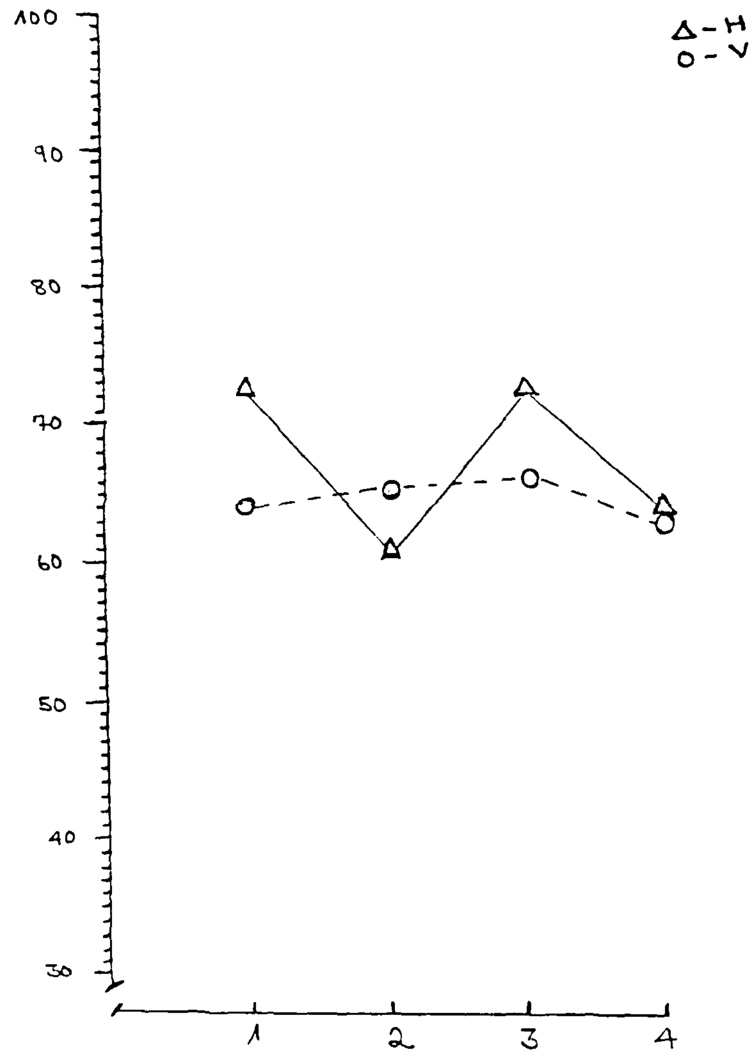

Figure 10: Percent Correct Recognition Responses for Horizontal and Vertical Orientations by Four Axes

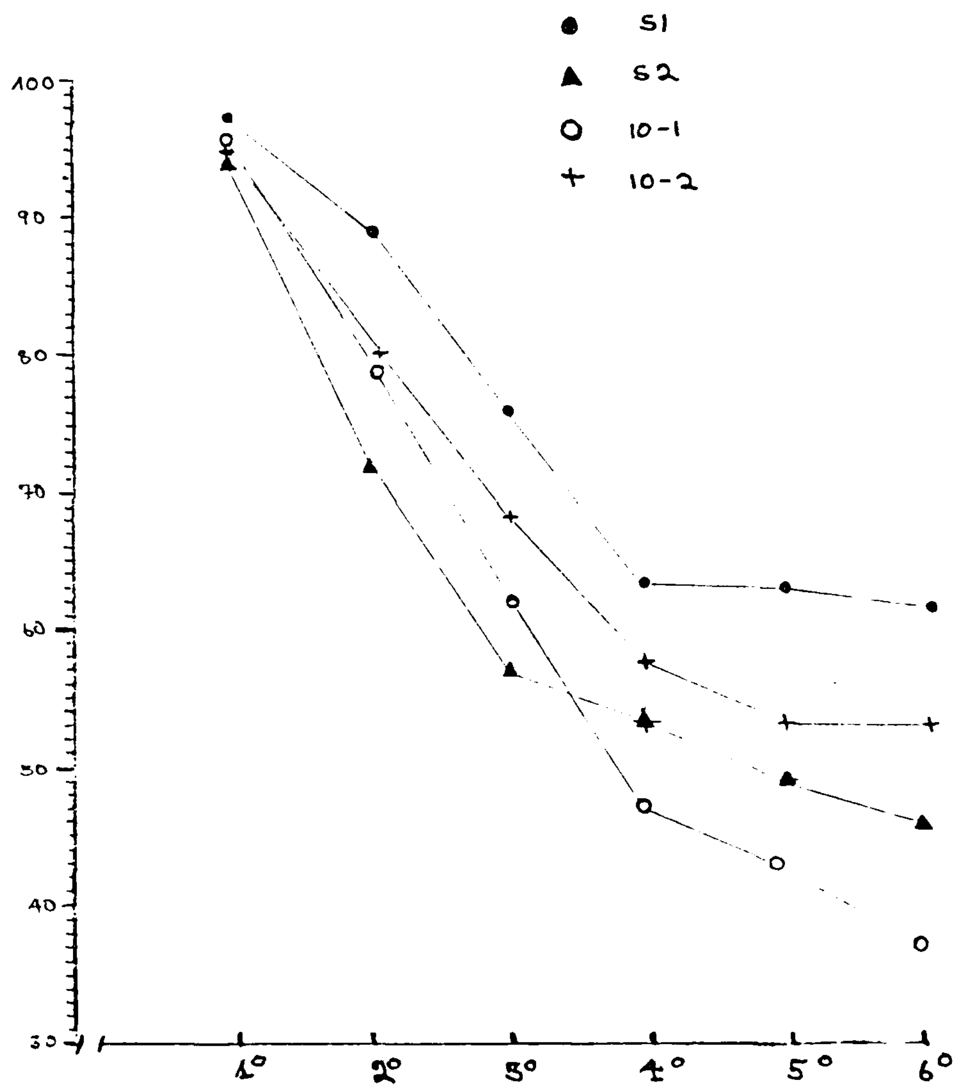

Figure 11: Percent Correct Recognition Responses for Two Texture Elements by Horizontal and Vertical Orientations for Six Distances from Foveal Center

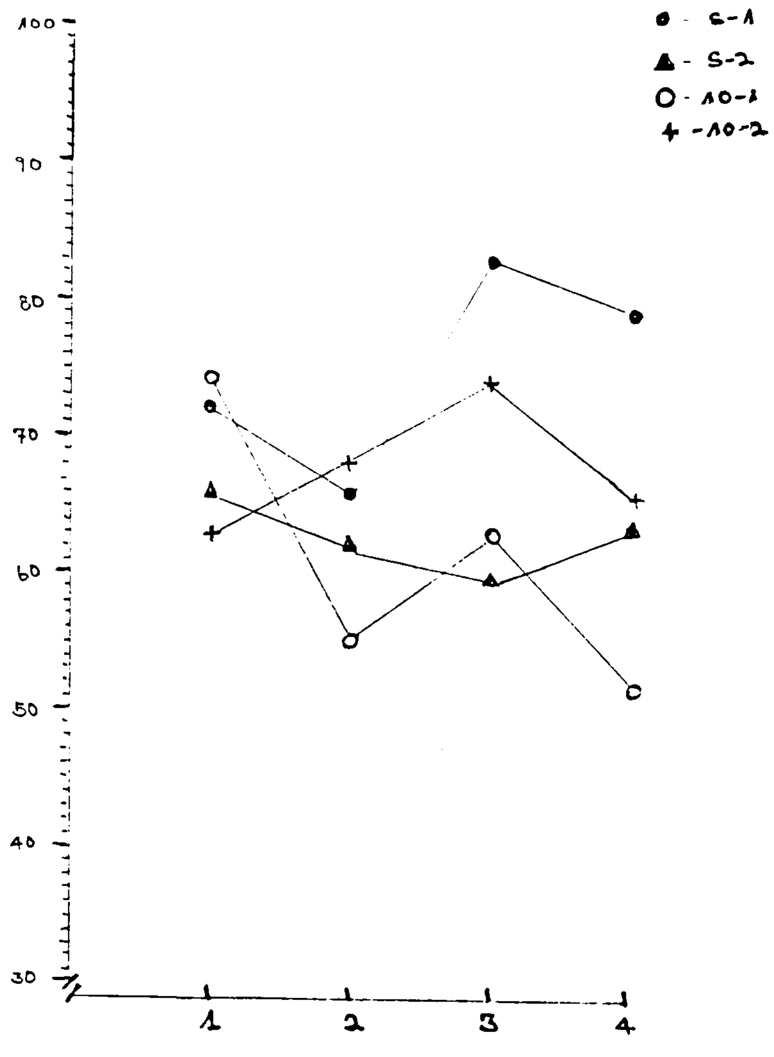

Figure 12: Percent Correct Recognition Responses for Two Texture Elements by Horizontal and Vertical Orientations for Four Axes

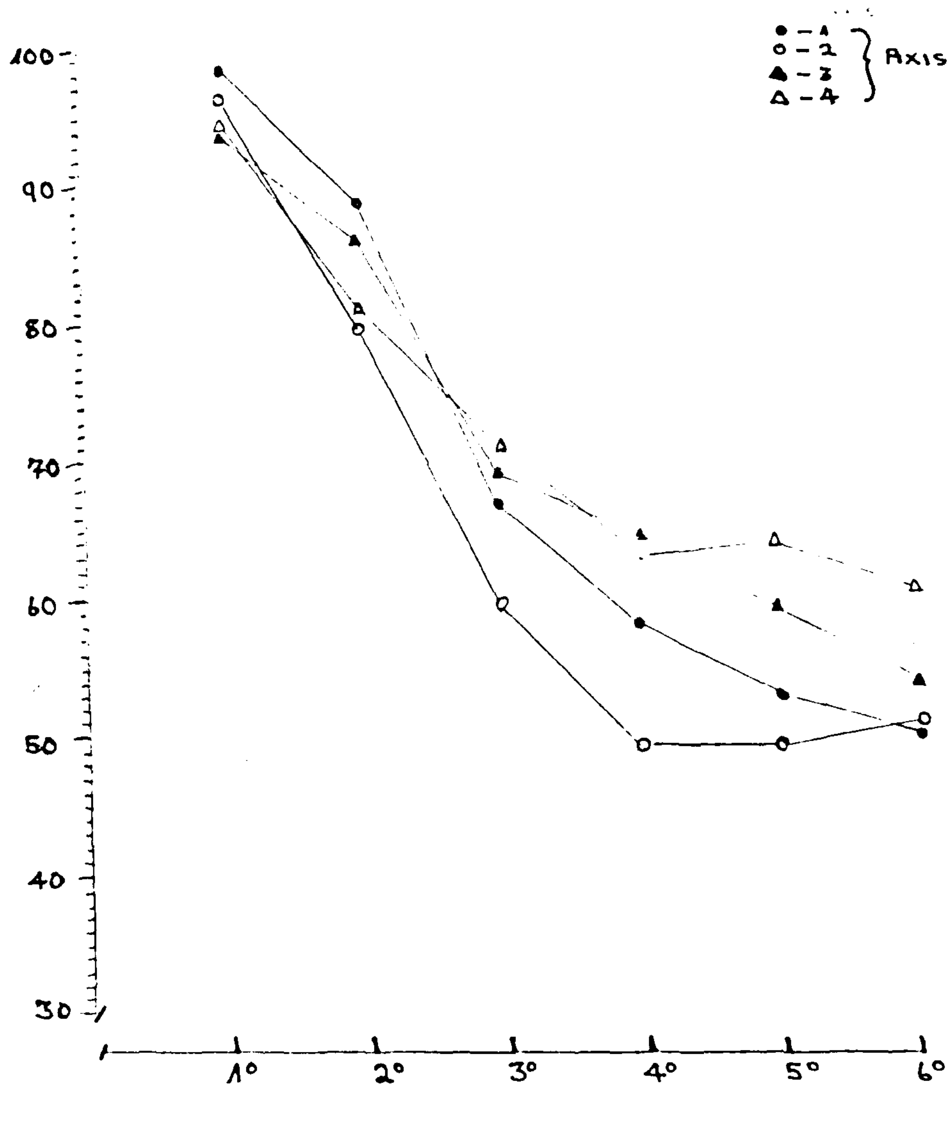

Figure 13: Percent Correct Recognition Responses for S Texture Element by Axis and Distance from Foveal Center

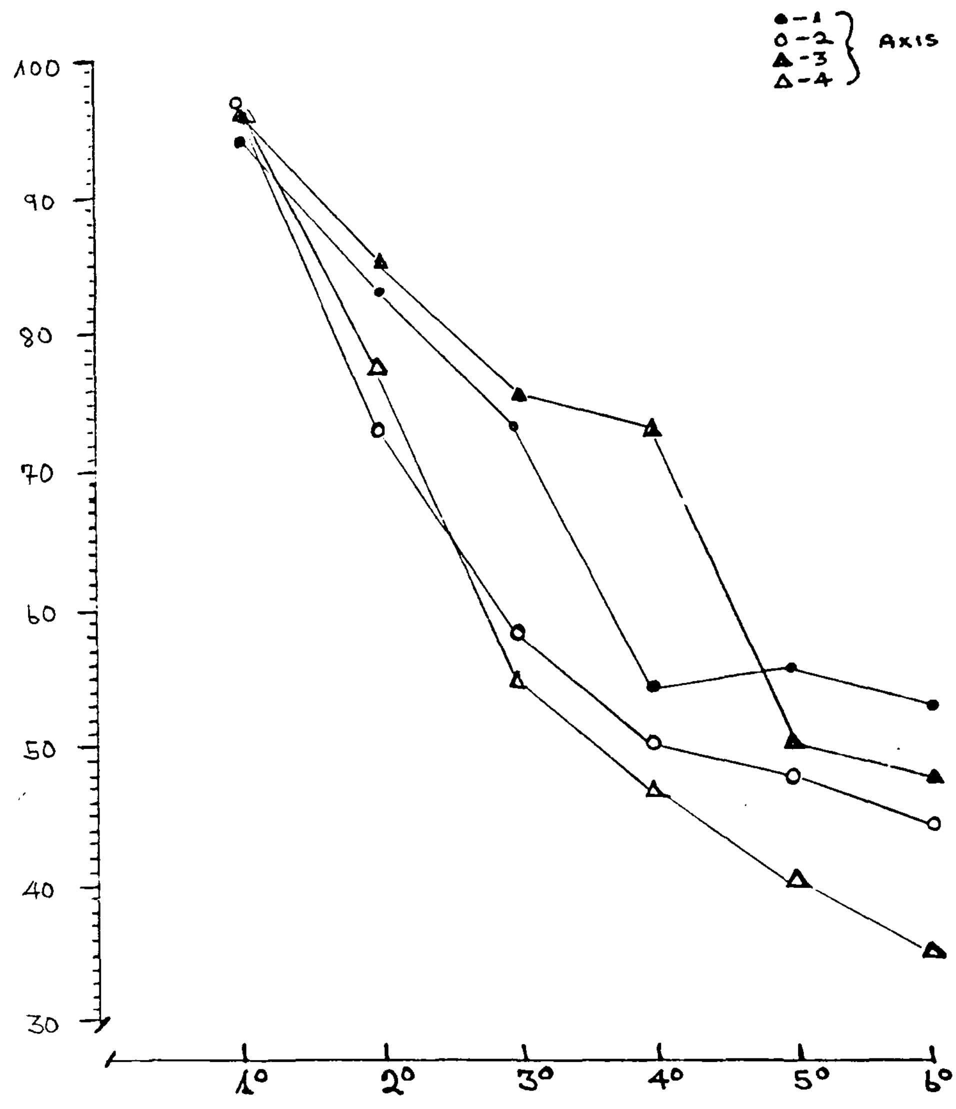

Figure 14: Percent Correct Recognition Responses for 10 Texture Element by Axis and Distance from Foveal Center

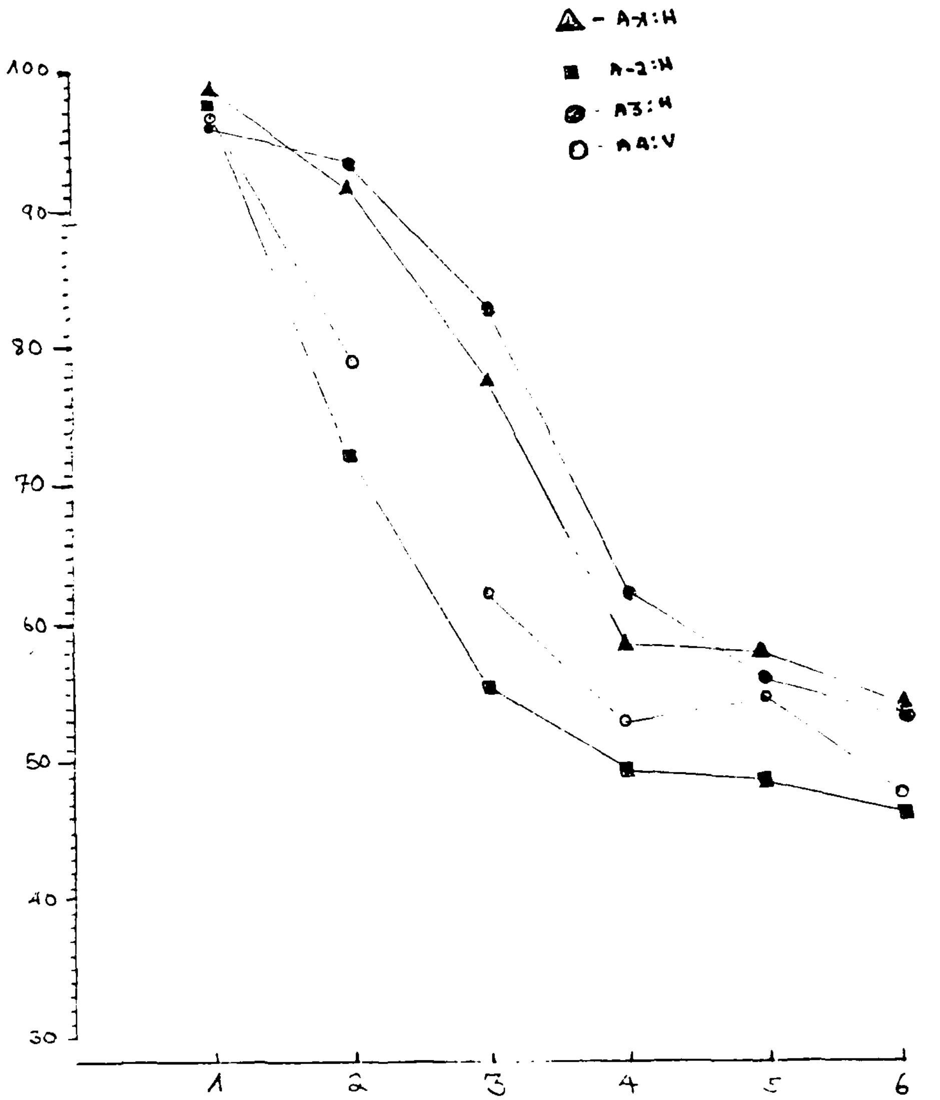

Figure 15: Percent Correct Recognition Responses for Orientation (Horizontal) by Axis and Distance from Foveal Center

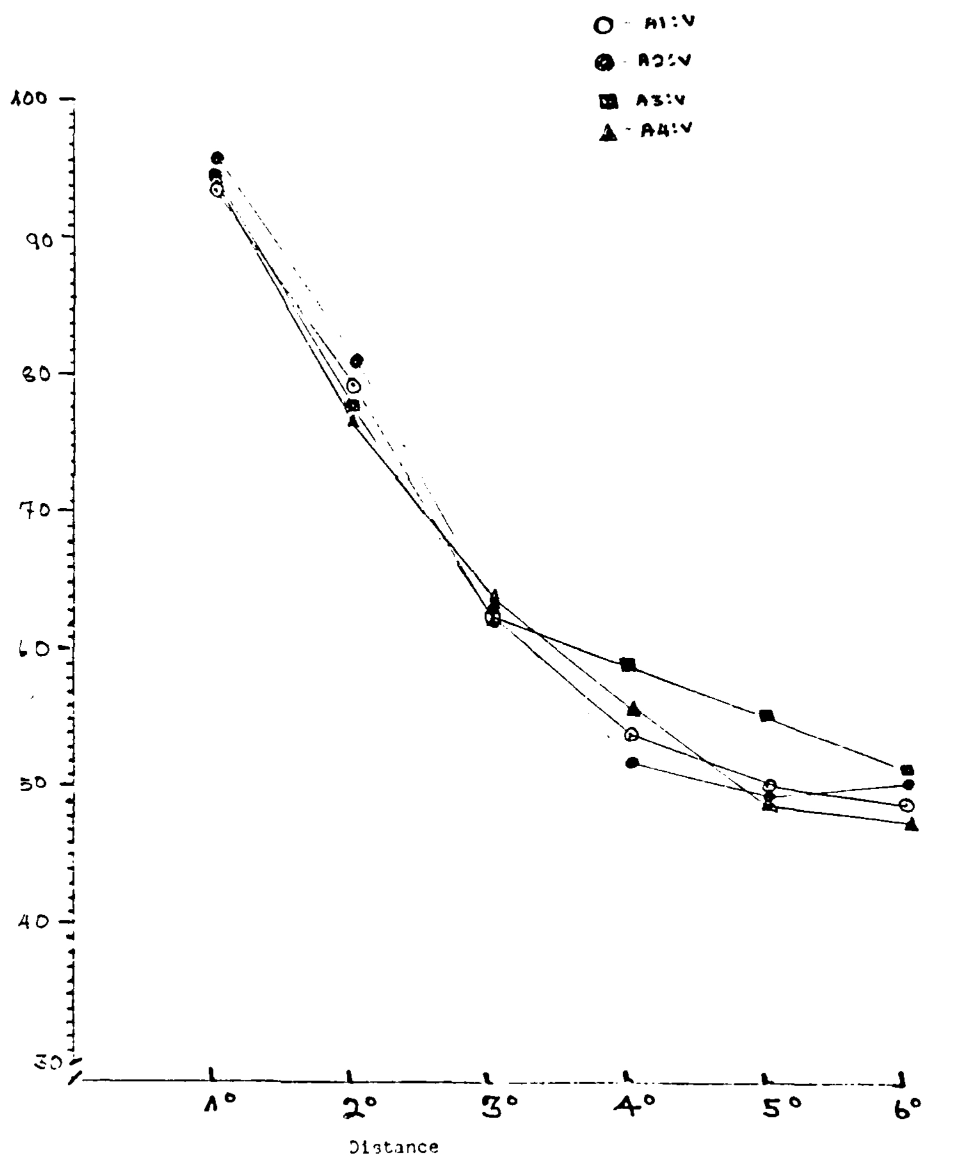

Figure 16: Percent Correct Recognition Responses for Orientation (Vertical) by Axis and Distance from Foveal Center

Table 4

EFFECT	df	F	P
Element	1/13	.4200	.528
Orien	1/13	3.333	.091
Axis	3/39	15.387	.000
Post	2/26	211.33	.000
El/Or	1/13	14.883	.002
El/Ax	3/39	.6434	.592
El/Po	2/26	.5526	.582
Or/Ax	3/39	9.127	.000
Or/pos	2/26	4.369	.023
Ax/Po	6/78	4.314	.001
E/O/A	3/39	17.335	.000
E/O/P	2/26	1.284	.294
E/A/P	6/78	2.502	.029
O/A/P	6/78	3.897	.002
E/O/A/P	6/78	4.185	.001

Table 5

EFFECT	df	F	P
Orien	1/13	9.907	.008
Axis	3/39	1.019	.394
Posit	2/26	70.82	.000
Or/Ax	3/39	5.297	.004
Or/Pos	2/26	6.323	.006
Ax/Pos	6/78	1.562	.169
O/A/P	6/78	1.945	.084

Anova Results for S Texture Figure

Table 6

EFFECT	df	F	P
Orien	1/13	.221	.646
Axis	3/39	6.953	.001
Posit	2/26	132.268	.000
Or/Ax	3/39	17.915	.000
Or/Pos	2/26	1.336	.280
Ax/Pos	6/78	5.528	.000
O/A/P	6/78	6.042	.000

Anova Results for 10 Texture Figure

These two MANOVAs reveal a different pattern of results for the S figure and the ten figure. Where we have a significant difference for Axis with the 10 texture figure there is no significant effect for the S texture figure on the Axis variable. The two way and three way interactions in the respective analyses also differ. The one constant finding in all the analyses run was the finding for a difference in distance from foveal center on recognition performance. In no analysis did we find an overall difference for texture figure S vs. 10.

7 Discussion:

It is clear from the data in this experiment that retinal position, (i.e. distance from foveal center), affects recognition performance (see Tables 3 & 4 and Figures 4 & 5) for non pre attentively discriminable texture elements. The data demonstrate that there is a rapid fall off in correct recognition response from one to three degrees from foveal center when inspection time for focal scrutiny is held constant at some 260msc. Recognition performance beyond three degrees from foveal center appears to flatten out as shown by figure five. These data suggest that any model of the allocation of focal attention within a fixation must be based on a modified probability formula that accounts for the greater recognition time required for scrutiny of elements beyond one degree from foveal center. This longer recognition time may be accounted for in part by the suggestion of Sterling & Salthouse that at distances away from foveal center percepts will take longer to form due to differences in receptor density or by the magnification factor discussed above where fewer cortical cells are stimulated when a stimulus of constant size is located further from foveal center.

Additionally, the results we obtained would appear to indicate that at least for some texture elements there is a strong effect on recognition performance with angle of eccentricity from foveal center. The MANOVA results in Table 3 indicate a strong effect, p=.000 for axis and the data plot in figure 9 would indicate that axes one and three give better recognition performance than do axes two and four. Differences for axes are also implicated in a number of two way and three way significant interactions in the data. Here the Sterling & Salthouse finding for differences in percept formation due to differences in receptor density do not fully explain this finding unless we assume that at certain angles away from foveal center receptor density will vary significantly enough to account for this finding. The same could be said for the possible effect of a magnification

factor since cortical cell distribution appears to be uniform.

Overall, given a constant stimulus size above acuity thresholds and a constant inspection time, recognition performance for the central fovea and near periphery is not uniform. This would suggest that the allocation of focal attention and scrutiny within a single fixation is not uniform. For scrutiny of elements within one degree from foveal center less time for focal attention is required for recognition to occur while for elements at greater distances and not on the same horizontal plane as the fovea greater time is required for recognition to occur.

7.1 Orientation Differences:

The effect we found in this data for orientation (i.e. either horizontal or vertical irrespective of correct phenomenal orientation) is less clear cut and more difficult to account for. In the first MANOVA we ran on this data (see table 3) findings indicated a significant effect for horizontal vs. vertical orientation of the combined texture elements at $p = .002$. Yet when the recognition data for this finding is plotted (see Figure 6) the differences between horizontal and vertical orientations does not appear to be that great. Both data lines track each other fairly closely. In light of this we rearranged the data matrix so as to contrast texture figures oriented in their correct semantic configuration (S & 10 combined) the MANOVA we ran did not show a significant effect for orientation (see table 4) $p=.091$. Yet the data plot for this effect in Figure 7 does seem to indicate a greater difference in correct versus incorrect semantic orientation of the figures than did the plot in Figure 6 for horizontal and vertical orientations. In the plot in Figure 7 the difference in correct recognition rates seems to increase with distance from foveal center. We should note that the analysis from the second MANOVA did indicate a significant effect for the two way interaction of orientation by element, $p=.002$ as well as significant effects for orientation by axis, $p=.000$ and orientation by position (distance from foveal center), $p=.029$. For both the S and 10 texture elements, distance away from foveal center does appear to increase the effect for different phenomenal orientation. Overall, these results, particularly the significant finding for the two way interaction of orientation by texture figure led us to do a further breakdown of the data analysis by looking at the two texture elements in separate analyses.

These individual analyses (see tables 5 & 6 and figure 8) demonstrated a significant effect for semantically correct vs. semantically incorrect orientation for the S texture element, $p= .008$ but no significant effect for the 10 texture element, $p=.646$. If we examine the plots in figure 8 we can observe that the differences for the S texture element are more pronounced for the semantically correctly oriented figure then in the plot for the 10 texture element. However, in both plots the semantically correctly oriented figures give better recognition rates than do the semantically incorrectly orientated figures. It is not unreasonable to conclude from this further analysis that the original significant finding for an orientation difference based on the horizontal and vertical comparison was an artifact due to combining the S and 10 texture elements in the analysis. This may be attributable to the fact that the analysis of spatial orientation for the figures is confounded with phenomenal orientation. In the case of the S texture element the correct semantic orientation is coincident with the horizontal orientation and in the case of the 10 texture element the correct phenomenal orientation is coincident with the vertical orientation. Given different results for the element considered separately it is plausible to assume that the lack of effect for the ten texture element overwhelms the analysis and no effect is observed for phenomenal orientation. Likewise in the finding for a significant effect for horizontal versus vertical orientation the combination of the strong difference in the S figure for a horizontal orientation, its correct semantic orientation, overwhelms the analysis and

gives us the result of an orientational difference that is epiphenomonial. Observation of the graphs in figure 8 shows that for the S texture element the horizontal orientation coincident with the correct phenomenal orientation shows better recognition rates. For the 10 texture element, the vertical orientation coincident with its correct phenomenal orientation shows the better recognition scores although the disparity between the orientations is less for this figure than for the S texture element. It may be that some combination of phenomenal orientation and spatial orientation accounts for the pattern of results in our data.

While this analysis is by no means conclusive, it would seem likely that given the independent analysis performed on the texture elements and in the absence of any other data, that phenomenal orientation does affect recognition at distances away from foveal center for at least the S texture figure to a significant extent and for the 10 texture element to a lesser extent but greater with increasing distance from foveal center. The overall effect for the 10 texture element is not as strong but the same trend is present. The question remains as to why there should be a difference for the texture elements. It may be the case that the percept of the S is simply more of an overlearned phenomena than the percept for the 10 element.

7.2 Axis Differences:

Throughout the findings from the various analyses we ran differences in recognition of the texture elements were implicated with differences in axis of presentation. In particular we have to note the significant effects for two way and three way interactions. These seem to suggest strongly that recognition is not simply a function of increasing distance from foveal center but rather is due to a complex interaction of several variables. One of the major variables implicated is axis of presentation. There were significant effects for axis as a main effect as well as for axis and distance from foval center (see figure 9) and orientation and axis (see figure 10) as significant two way effects. The analysis of the data also demonstrated a significant three way effect for texture element by orientation of element by axis (see figure 12). In most cases but not all the recognition performance for axes one and three, the two horizontal axes was better than recognition performance on axes 2 and 4. The mean percent correct recognition rates for the four axes are given in table 7 below. These data are also plotted in figure 17 below.

Table 7

Axis	Mean	Variance	Standard Deviation
1	.54	.336	.18
2	.53	.376	.14
3	.72	.420	.20
4	.55	[illegible]	.21

Mean, Variance and Standard Deviation for Percent Correct Recognition Responses for all Subjects, N=336

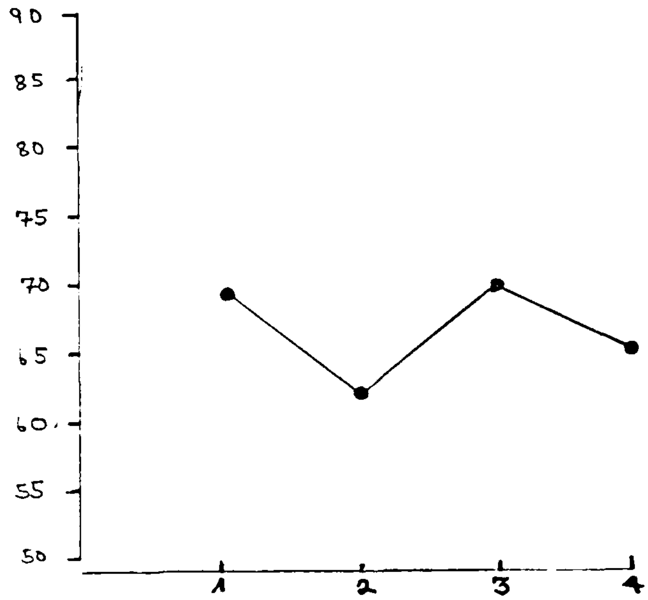

Figure 17: Percent Mean Correct Recognition Responses for Four Axes for all Texture Elements for all Subjects

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Figure 17 in which the two texture figures are combined shows a systematic variation among percent correct recognition responses for the four axes. Axes one and three yield better recognition performance. When we examined the S and 10 texture elements independently this pattern of variation of recognition performance where axes one and three showed better recognition performance holds for the correct phenomenal orientation of the S texture element (horizontal) and for the correct phenomenal orientation of the 10 texture element (vertical). This pattern can be observed in Figure 12 above. Figure 10 which plots percent correct recognition rates for horizontal and vertical orientations irrespective of texture element shows this pattern of variation for axes one and three versus two and four only for the horizontal orientation. It is likely that the strong effect for correct phenomenal orientation (horizontal) for the S texture element affects these results as indicated in our remarks on orientation differences above.

The pattern of findings for axes differences suggests strongly that recognition performance for the S and 10 texture figures are different with respect to axis of presentation for correct phenomenal orientation. We probably can conclude that orientation differences are strongly implicated in the observed axis difference where recognition performance is better for axes one and three on the horizontal plane. It is conceivable that the correct percents for S and 10 texture elements are more easily disrupted at axes two and four in the vertical plane. There are differences for axes for the incorrect phenomenal orientations of the texture elements but the differences here do not repeat the pattern of differences for correct phenomenal orientation. We can observe in Figure 12 that for the incorrect orientations the plot for the 10 texture element is a mirror image for the plot of recognition responses across the four axes for the S texture element. The pattern of correct recognition responses for the S element shows a steady decline from axis one through three with a recovery on axis four while the pattern for the 10 element shows a steady rise in correct recognition responses across axes one through three and a decline at axis

four. It is difficult to conjecture why there should be a difference either based on correct and incorrect phenomenal orientations or based on texture figure for the incorrect phenomenal orientations. We can only speculate that these various texture figures either give rise to different patterns of stimulation on retinal receptors that differ across the retina or that higher recognition centers in the visual cortex respond differently in forming a recognition response for stimulation by different texture elements at various retinal eccentricities.

7.3 Recognition & Search Performance

Given the findings in the experiment reported here of different correct recognition rates for non pre attentively discriminable texture elements at various distances from foveal center and at different orientations and eccentricities, it seems clear that allocation of focal attention to individual elements in the retinal array during fixation is not uniform. It is unlikely that this process of focal attention allocation is best modeled by a random walk model. Two models of the allocation of focal attention during fixation are consistent with the data from this experiment.

The first model assumes a fixation window of approximately three degrees in diameter. Such a fixation size will take in approximately nine to sixteen texture elements during fixation. Given the limiting factor of some 250msc. for fixation not all texture elements falling within the fixation area can be scrutinized. Focal attention is allocated to texture elements based on a modified random walk where progressively more time for scrutiny is allocated to elements as they exceed one degree from foveal center or are out of correct phenomenal orientation, or appear at angles of eccentricity that depart from the horizontal plane as determined by the viewers position.

The second model assumes that in a task where focal attention must be devoted during fixation to individual elements the size of the fixation window is adjusted so that fewer elements are taken in for scrutiny during any given fixation. Ideally this window size should be proportional to the amount of time available for scrutiny during fixation. Given the data from this experiment estimates of the size of this fixation window cannot be determined. However, we can conjecture that such a fixation window should be less than three degrees in diameter.

Of the two models proposed above the second is consistent with other strategies we have observed in search behaviour. In our previous work, Scinto et al., 1986 we observed that as search continued to be unsuccessful subjects adjusted two aspects of the allocation of molar attention. Saccade amplitude was reduced and fixation time was increased. It is not at all unlikely that a further adjustment is made in the spatial extent of the functional visual field of the fixation.

Both of these models could be tested by modifying the simulated search algorithm we developed in our earlier study (Scinto, et al., 1986). The cumulative detection curves each of the models produce could then be compared to actual search data from our previous study. We had hoped to carry out this simulation but the unavailability of the BRD computer on which the original algorithm was mounted prevented any test of these models.

The data from this study does help to clarify further the nature of the strategies used in visual search for hidden or non pre attentively discriminable targets.

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